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The Maximum Oxygen Intake*

An International Reference Standard of Cardiorespiratory Fitness

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Lack of cardiorespiratory fitness may well contribute to the increasing prevalence of degenerative cardiovascular disease throughout the world. As a first step towards co-ordinated and internationally comparable investigation of this problem, methods of measuring the reference standard of cardiorespiratory fitness—the maximum oxygen intake, $(\dot{V}_{O_2})_{max}$—were compared by an international working party that met in Toronto in the summer of 1967.

Repeated testing of 24 subjects showed that the $(\dot{V}_{O_2})_{max}$ was greatest on the treadmill, 3.4 % smaller in a stepping test, and 6.6 % smaller during use of a bicycle ergometer. There were also parallel differences in cardiac stroke volume. Uphill treadmill running was recommended for the laboratory measurement of $(\dot{V}_{O_2})_{max}$, and stepping or bicycle exercise for field studies. A discontinuous series of maximum tests caused some improvement in the fitness of subjects, and a "continuous" test (with small increases in load at 2-min intervals) was preferred.

The prevention of cardiovascular disease currently presents a major challenge to world health. Furthermore, there is increasing evidence to link certain forms of cardiovascular disease with habitual inactivity and lack of cardiorespiratory fitness. Since physical inactivity is an ever-increasing feature of modern society, it is important to obtain additional evidence on this point, to compare the fitness of communities differing in habitual activity, economic and nutritional status, and to initiate longitudinal studies of the fitness of communities as they pass from a rural to an urban mode of life. However, a fundamental requirement for such investigations is an internationally agreed reference standard of cardiorespiratory fitness. With a view to reaching a decision on this matter, an international working party was convened in Toronto in the summer of 1967, under the auspices of the International Biological Programme. The parameter selected for measurement was the maximum oxygen intake—$(\dot{V}_{O_2})_{max}$. Three commonly used laboratory modes of exercise (stepping, cycling, and treadmill running) were compared, using both "discontinuous" and "continuous" patterns of exercise, and agreement was reached on optimum procedures for laboratory and field use ("continuous" tests involving uphill treadmill running and stepping or bicycle exercise respectively). The results on which this choice is based are presented here.

MATERIAL AND METHODS

Subjects and experimental plan

The subjects were 24 Canadian men (age range 20–40 years, mean 26.4 years), varying in fitness from sedentary desk-workers to university class athletes; their maximum oxygen intake ranged from 30.6 ml/kg/min to 69.1 ml/kg/min, with a mean value of 49.4 ml/kg/min. Each subject carried out a preliminary 2-week conditioning programme of submaximum exercise. Maximum exercise was then performed at the same hour on each of 10 successive working days, with a final maximum test during the following week. Initial resting conditions were thus relatively constant for each subject. None was involved in heavy manual labour, and no measurements were made earlier than one hour after a meal. The mode

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and pattern of exercise for a given subject on a given day were selected according to the pre-established experimental design presented in Table 1.

TABLE 1

EXPERIMENTAL DESIGN FOR 6 GROUPS OF SUBJECTS PERFORMING STEP (ST), BICYCLE ERGOMETER (BI) AND TREADMILL (TM) EXERCISES

Day	Group					
	1	2	3	4	5	6
1–3 (discontinuous test)	ST	ST	BI	BI	TM	TM
4–6 (discontinuous test)	BI	TM	ST	TM	ST	BI
7 (continuous test)	TM	BI	TM	ST	BI	ST
8–10 (discontinuous test)	TM	BI	TM	ST	BI	ST
11 (continuous test)	TM	BI	TM	ST	BI	ST

The international team of observers included experienced proponents of step, bicycle, and treadmill tests. Each of the visiting scientists achieved the best results he could with the procedure of his choice, but no attempt was made to introduce the complication of rotating scientists between the three testing rooms.

Modes of exercise

A single step, 18 inches (46 cm) high, was climbed with two paces. The stepping rhythm was controlled by metronome at 80–140 paces/min, depending upon the fitness of the subject.

The bicycle ergometer was a Fleisch Ergostat (Jacquet Ltd, Basle, Switzerland). The saddle height was adjusted to allow full extension of the leg during cycling, but the subject was not permitted to stand on the pedals. The pedal speed was controlled at 60–90 revolutions per minute, depending upon the fitness of the subject.

The treadmill exercise was uphill running at speeds of 5–6 mi/h (8–9.6 km/h), on slopes of 1%–18%, depending upon the fitness of the subject. A safety mat was provided, and the observer gave gentle support as necessary when co-ordination became impaired.

Pattern of testing

Irrespective of the type of test to be performed, the initial routine comprised 15 min rest, 5 min " warm-up " exercise at approximately 50% of the individual's aerobic power, and a further 5 min rest. In the discontinuous maximum test, the first load chosen was equivalent to 110% of the aerobic power, as predicted from the response to the " warm-up " and previous submaximum tests; the loading on subsequent days was adjusted upward or downward in the light of performance on this occasion. Pulse rates and gas samples were obtained not earlier than 2 min, and preferably 3–4 min, after commencing maximum exercise. In the continuous maximum tests, the routine was similar, except that the initial load was 90%–100% of the individual's predicted maximum, the exercise load was increased slightly at the end of each second minute, and the pulse rate and gas samples were obtained during the final 30 s at each intensity of exercise.

Physiological measurements

The pulse rate was calculated from recordings of the parasternal electrocardiogram. A low resistance McKerrow valve box (dead space < 50 ml) and a short length of smooth-walled tubing (internal diameter 1.5 in; 3.8 cm) conducted expired gas into broad-necked meteorological balloons. Samples for gas analysis were taken into 100-ml glass syringes, and the volume of gas within the bags was then measured by transfer to a Tissot spirometer or a recently calibrated dry-gas-meter. The oxygen and carbon dioxide contents of the gas samples were determined by paramagnetic and infra-red analysis respectively. Both machines were calibrated frequently, using known gas mixtures determined on a Lloyd-Haldane apparatus.

The lactate content of the blood was estimated using a scaled-down version of the standard Boehringer enzymatic procedure (see Annex). Samples of arterialized capillary blood (100 μl) were drawn from the heated finger-tip 2 and 4 min after completion of maximum exercise.

Cardiac outputs were measured in 8 of the more co-operative subjects, using an acetylene rebreathing method (Simmons, 1968). Gas from a bag containing initially 1500 ml of 1% acetylene in 25% oxygen was rebreathed at a rate of one breath per second during the final 7–10 s of each bout of maximum exercise. Samples collected in 10-ml syringes at the end of the fourth and seventh breaths were analysed for oxygen, nitrogen, and acetylene, using a gas chromatograph with twin glass columns (silica gel and molecular sieve). The arteriovenous oxygen difference was calculated according to the Grollman formula (Grollman, 1929), using revised solubility coefficients for acetylene (Simmons, 1968). The cardiac output was determined by relating the arteriovenous oxygen difference to the oxygen consumption measured immediately beforehand.

RESULTS

Optimum mode of exercise

Maximum oxygen intake. It was accepted that a maximum oxygen intake had been achieved when, with further increase of work-load, the oxygen consumption increased by less than 2 ml/kg/min; in most cases, the subsidiary criteria of a post-exercise lactate concentration >100 mg/100 ml and a pulse rate within 2 standard deviations of the expected maximum value were also met.

The figures quoted in Table 2 are based on the mean of 2 or 3 such plateau values for each of the 24 subjects performing discontinuous maximum exercise tests on each of the 3 forms of apparatus. Uphill treadmill running gave a maximum oxygen intake 3.4% larger than that found during stepping, and 6.6% larger than that during cycling. Although numerically small, these differences conformed with previous comparisons of cycling and uphill treadmill running (Wyndham et al., 1966; Glassford et al., 1965; Saltin & Åstrand, 1967), and were of considerable statistical significance ($P < 0.01$ and $P < 0.001$ respectively). They may be examined further in terms of the attitude of the subjects, the motivating power of the observers, and the relative importance of peripheral and central exhaustion in the 3 test situations.

TABLE 2

COMPARISON OF DISCONTINUOUS BICYCLE, STEP AND TREADMILL TESTS [a]

Exercise	$(\dot{V}_{O_2})_{max}$ (litres/min STPD [b])	Pulse rate, f_h (beats/min)	Lactate (mg/100 ml)
Treadmill	3.81±0.76 (2.54–5.84)	190±5 (178–197)	122±21 (78-166)
Bicycle	3.56±0.71 (2.57–5.23)	187±9 (167–207)	112±15 (89–143)
Step	3.68±0.73 (2.66–5.59)	188±6 (170–195)	105±26 (45–165)

[a] n = 24; the figures represent the mean of 2 or 3 plateau values ± the standard deviation (with range in parentheses).

[b] Standard temperature and pressure, dry.

Attitude of subjects. Eleven of the 24 men expressed a preference for the treadmill test, 9 preferred the bicycle ergometer, and 5 the step test. The main complaints against the treadmill were the lack of any opportunity to rest, and the need to keep in one position on the belt; a few also found the belt slippery. The main problem with the bicycle was saddle discomfort; in common with most bicycle ergometers, the Fleisch Ergostat had a broad saddle, totally unlike the narrow designs preferred by racing cyclists. Some subjects also found that the saddle pillar was too nearly vertical, and that the handlebars were too high, while a few complained of difficulty in maintaining the pedal rhythm. The 18-in step was found rather high by some subjects, and others complained that this form of exercise was boring. Some subjects found difficulty in maintaining a rapid rhythm; there were complaints that the steps seemed slippery, and tripping tended to occur as the subjects became exhausted.

Motivating power of the observers. All three teams had considerable experience in the measurement of maximum oxygen intake, and the majority of subjects were well motivated. A substantial difference in external motivation was thus unlikely.

The combined effects of the attitude of the subjects and the motivating power of the observers can be examined in terms of physiological responses to " maximum " exercise (Table 2); both terminal pulse rate and post-exercise lactate concentrations were marginally lower in step and bicycle exercises than in the treadmill tests.

Limiting factors at exhaustion. Towards the end of treadmill exercise, subjects complained of nausea, breathlessness, and chest pain, looked intensely cyanosed, and in some cases became unsteady on their legs; local pain in the leg muscles was never described. During exercise on the bicycle ergometer, weakness or pain localized in the quadriceps muscle was an unanimous complaint; a few subjects also complained of breathlessness, but the facies of circulatory exhaustion was not seen. Stepping exercise seemed intermediate between treadmill and bicycle exercise in this respect. Some subjects complained of weakness or pain in the leg muscles, but in others loss of co-ordination and dyspnoea were the dominant factors. On clinical grounds, it might thus be concluded that the factor limiting treadmill exercise was central exhaustion, that bicycle exercise was limited by local exhaustion, and that stepping was limited by a combination of the two forms of exhaustion.

It was only practical to measure cardiac output during treadmill and bicycle exercise. The maximum cardiac output and the maximum stroke volume were both significantly greater during treadmill running than during exercise on the bicycle ergometer (Table 3). However, the maximum arteriovenous oxygen difference was similar for the two forms of work.

The influence of repeated tests on cardiorespiratory fitness

One possible objection to the estimation of cardiorespiratory fitness by a series of discontinuous maximum tests is that the exercise involved may alter the parameter that is being measured. This point was next examined.

In order to permit easy comparison between the 6 arbitrary groups of subjects, the maximum oxygen intakes were scaled to yield a common mean value of 3.63 litres/min for each group. Data were then classified according to the order of testing (Table 4). There was a small over-all increase in maximum oxygen intake over the 7 test days from the first to the third group of experiments (gain of 0.18 litre/min, or about 5%). There was also some suggestion that, whereas treadmill exercise improved subsequent performance on the step and bicycle tests, the reverse was not true.

In contrast with the increase in maximum oxygen intake, the lactate concentrations remained remarkably constant with repetition of the tests. The change in oxygen intake thus represents a true gain in fitness rather than greater relative exertion on the part of the subjects.

A comparison of continuous and discontinuous maximum exercise

Discontinuous tests pose two practical problems: (*a*) fitness may change while the measurements are being made, and (*b*) busy subjects may not be willing to return to the laboratory on the three or more occasions required for testing. Accordingly, it was decided to see how far the results of the discontinuous tests could be duplicated by a single continuous test.

Two comparisons were made (Table 5). The first was based on the practical field situation, where the observer had no guidance, other than results of the "warm-up" period, in choosing suitable work loads. Despite this disadvantage, the maximum oxygen intake was not significantly less than in the subsequent discontinuous test. The difference observed (−2.4%), even if substantiated by tests on a larger

TABLE 3

HIGHEST VALUES OF CARDIAC OUTPUT, STROKE VOLUME, AND ARTERIOVENOUS OXYGEN DIFFERENCE FOR TREADMILL (TM) AND BICYCLE ERGOMETER (BI) EXERCISE

Subject	Maximum cardiac output (litres/min)			Stroke volume (ml)			Arteriovenous oxygen difference (ml O_2/100 ml blood)		
	TM	BI	Δ[a]	TM	BI	Δ	TM	BI	Δ
3	27.5	23.2	4.3	141	127	14	14.1	14.8	−0.7
9	24.5	24.6	−0.1	141	144	−4	12.8	12.8	0
10	22.7	21.5	1.2	119	114	5	12.6	12.4	0.2
12	32.2	26.1	6.1	172	140	32	15.4	14.2	1.2
13	28.3	25.6	2.7	164	149	15	13.6	14.0	−0.4
14	28.1	24.6	3.5	144	119	25	14.2	13.7	0.5
15	37.3	35.3	2.0	184	178	6	15.6	14.8	0.8
26	25.7	23.7	2.0	137	128	9	13.6	14.0	−0.4
Mean ±S.D.	28.3	25.6	2.7[b]	150	137	13[c]	14.0	13.8	0.2
	±4.7	±4.2	±1.9	±21	±20	±11	±1.1	±0.8	±0.7

[a] Δ = difference. [b] Statistically significant ($P < 0.001$). [c] Statistically significant ($P < 0.01$).

TABLE 4

EFFECT OF REPEATED PERFORMANCE OF THE MAXIMUM OXYGEN INTAKE TEST ON MAXIMUM OXYGEN INTAKE (OR $(\dot{V}_{O_2})_{max}$) [a] AND ARTERIAL LACTATE (mg/100 ml)

Mode of exercise	Order of test: First (days 11–13)		Second (days 14–16)		Third (days 17–20)	
	$(\dot{V}_{O_2})_{max}$	Lactate	$(\dot{V}_{O_2})_{max}$	Lactate	$(\dot{V}_{O_2})_{max}$	Lactate
Treadmill	3.77	123	3.85	124	3.68	124
Step	3.42	106	3.46	92	3.79	99
Bicycle	3.39	113	3.60	112	3.67	111
All tests	3.53	114.0	3.64	109.3	3.71	111.3

[a] Values for $(\dot{V}_{O_2max})$ have been adjusted to allow for small differences in endurance fitness between the arbitrary groupings of subjects.

group of subjects, could be attributed largely to a continuation of training from Day 7 to Day 9.

The second series of continuous tests was performed with full knowledge of loadings from the discontinuous tests. Under these circumstances, the continuous tests gave a slightly higher maximum oxygen intake (average +2.7%). Again, larger numbers of subjects would be needed to establish this statistically, and at least part of the difference could be attributed to a continuation of training.

DISCUSSION

The reference standard

Although many tests of cardiorespiratory fitness have been proposed in the past few decades, the opinion is now widespread that the directly measured $(\dot{V}_{O_2})_{max}$ should be accepted as the absolute criterion against which other procedures are to be judged. In physiological terms, this view seems indisputable, for the $(\dot{V}_{O_2})_{max}$ integrates the performance of each of the several " conductances " concerned in the transfer of oxygen from the atmosphere to the working tissues (Shephard, 1968). However, before accepting the $(\dot{V}_{O_2})_{max}$ as an international standard of reference, it is important to ensure also that the measurement is practical, and yields reproducible values.

All of the present group of young men achieved a satisfactory $(\dot{V}_{O_2})_{max}$, irrespective of the mode of

TABLE 5

COMPARISON OF CONTINUOUS AND DISCONTINUOUS MAXIMUM TESTS [a]

Type of exercise	Discontinuous test: $(\dot{V}_{O_2})_{max}$ (litres/min STPD [b])	Pulse rate, fh (beats/min)	Lactate (mg/100 ml)	Continuous test: $(\dot{V}_{O_2})_{max}$ (litres/min STPD)	Pulse rate, fh (beats/min)	Lactate (mg/100 ml)	Continuous test (no prior information): $(\dot{V}_{O_2})_{max}$ (litres/min STPD)	Pulse rate, fh (beats/min)	Lactate (mg/100 ml)
Treadmill ($n = 7$)	3.59±1.32 (2.54–5.84)	186±5 (178–195)	123±15 (112–150)	3.69±1.14 (2.54–5.77)	185±10 (167–197)	79±19 (48–104)	3.70±1.22 (2.41–5.98)	186±5 (179–196)	114±20 (94–149)
Bicycle ($n = 8$)	3.79±0.61 (3.05–4.69)	187±6 (179–198)	111±7 (100–123)	3.82±0.77 (2.85–4.94)	187±5 (178–195)	76±15 (54–99)	3.55±0.60 (2.58–4.30)	181±9 (170–195)	101±21 (65–130)
Step ($n = 9$)	3.81±0.60 (2.93–4.85)	189±4 (184–195)	99±19 (68–129)	3.97±0.71 (2.81–5.04)	185±6 (175–195)	81±21 (58–103)	3.71±0.55 (2.81–4.62)	186±6 (175–195)	97±25 (70–141)
All tests ($n = 24$)	3.74	187	110	3.84	186	79	3.65	185	103

[a] The figures represent the mean ± the standard deviation (with the range in parentheses).

[b] Standard temperature and pressure, dry.

exercise. However, it is unrealistic to suggest that the $(\dot{V}_{O_2})_{max}$ be measured directly for entire populations. More difficulty would be encountered in reaching a maximum with the very young, the elderly, and female subjects, while the logistic requirements in terms of medical supervision would be prohibitive. Nevertheless, it seems likely that within any given population there will be an adequate number of individuals who are able and willing to perform a $(\dot{V}_{O_2})_{max}$ test, thus providing a reference standard against which secondary and more widely applicable tests may be calibrated.

The stability of an individual's $(\dot{V}_{O_2})_{max}$ for a given mode of exercise is largely a matter of good technique. Thus measurements must not be made following a heavy meal, previous exercise, or exposure to heat. The initial condition of the subject (resting or basal) must be specified. The subjects must be well motivated. The duration of exercise must be sufficient to reach a steady state of oxygen consumption, and objective evidence of an " oxygen consumption plateau " must be obtained. The apparatus for collecting expired gas must have a low dead space and low resistance. Gas must be collected without leakage at the mouth-piece, and gas analysis performed without systematic error. Relatively few differences in procedure were found between the scientists cooperating in the present project; however, all were drawn from laboratories with considerable experience. To ensure the reproducibility of the $(\dot{V}_{O_2})_{max}$ values when measured by a wider range of laboratories, it will be necessary to specify procedures in some detail (as in the forthcoming *Handbook of Methodology for the International Biological Programme*—Weiner, 1968), and to offer facilities for the learning of techniques in appropriate reference laboratories.

The mode of exercise

It is generally agreed that, to achieve the $(\dot{V}_{O_2})_{max}$, a subject must exercise a substantial proportion of the large muscles of the body. However, there is no agreement on the type of exercise to be performed (step, bicycle ergometer, or treadmill) or on suitable combinations of rhythm and intensity of effort. There have been occasional comparisons of two forms of maximum exercise (for references, see Shephard, 1966; Kasch et al., 1966; and Wyndham et al., 1966), but no one has previously compared the responses of the same subjects to all three common modes of testing. Attempts to vary both the rhythm and the mode of exercise would have produced an unnecessarily complicated experimental design; hence, in the present study, the stepping rate, pedalling speed and running speed were each set at a rhythm that seemed natural and comfortable for the subjects concerned.

The differences in $(\dot{V}_{O_2})_{max}$ between the three forms of exercise are sufficiently small for inter-conversion of the data to be contemplated, using an appropriate scaling factor. The main weakness of such a mathematical manipulation is that the end-point does not seem the same for bicycle and for treadmill exercise. If performance on the bicycle ergometer is limited mainly by exhaustion of the quadriceps muscles rather than by general circulatory exhaustion, the extent of this weakness (and hence the discrepancy as compared with treadmill and step-test results) may vary with the extent of training of this particular muscle, and thus with previous use of the bicycle. In view of widespread cultural differences in the popularity of the bicycle as a mode of transport, this may prove a significant argument against performance of maximum tests on the bicycle ergometer. On the other hand, since none of the present subjects had ridden a bicycle for many years, the population studied may represent the upper limit of discrepancies between bicycle and treadmill tests.

In comparing maxima for the three forms of test, two final points should be emphasized: (1) The Fleisch Ergostat (in common with most commercial ergometers) is not an optimum design for maximum exercise, and (2) an older population with deterioration of the knee-joint might find it less easy to reach general circulatory exhaustion on a step test.

In the laboratory situation, there is much to commend the treadmill for the measurement of the $(\dot{V}_{O_2})_{max}$. Exercise is terminated at the desired point of general exhaustion, and the maximum oxygen intake achieved is larger than by the other two procedures. However, the apparatus is bulky, noisy, expensive, and not readily transported. Thus in field experiments a step test is probably the most suitable form of exercise. It is familiar to most populations, it can be made very cheaply, and does not require calibration. The only serious disadvantage of the step test by comparison with the bicycle ergometer is that it is more difficult to make ancillary measurements such as cardiac output. Such measurements are not commonly required under field conditions, and in choosing between a step test and a bicycle test the virtues of body immobilization must be weighed carefully against the simplicity of stepping exercise.

The arm ergometer was not included in these comparisons. Some authors (Åstrand & Saltin, 1961) have found a substantially smaller $(\dot{V}_{O_2})_{max}$ for arm exercise, but others (Nowacki & Mellerowicz, 1966) have reported no difference between handle and bicycle ergometry. From the present authors' experience of the hand ergometer, they would conclude that much depends upon the size of the crank. If a true circulatory maximum is to be reached during arm exercise, the subject must stand, and use not only his arms but the trunk musculature as well. Such a procedure may have clinical applications, particularly in the testing of subjects with paralysis of the legs, but it seems difficult to standardize and could not be recommended as the reference procedure for measurement of $(\dot{V}_{O_2})_{max}$.

Choice of pattern of exercise

The present observations confirm that it is possible to achieve a true $(\dot{V}_{O_2})_{max}$ through a procedure where the load is increased every 2 minutes. It is also practical to carry out such a procedure, even when prior knowledge of a subject's ability is limited to his performance during the initial " warm-up ". Pirnay et al. (1966) and Wyndham et al. (1966) recently reached similar conclusions. A rather longer period might be required to reach a steady state in patients where the circulation time was increased; however, such patients would not normally be expected to perform a maximum exercise test.

The cardiac output

The difference in maximum cardiac output between treadmill and bicycle exercise mirrored the previously noted difference in $(\dot{V}_{O_2})_{max}$, supporting the contention (Shephard, 1968) that cardiac output is the main determinant of the $(\dot{V}_{O_2})_{max}$. The difference in cardiac output was due almost entirely to a difference in stroke volume, suggesting that venous return was greater during treadmill exercise. However, the data leave unanswered the intriguing question whether the same stroke volume might have been achieved on the bicycle ergometer if exercise had not been terminated by local exhaustion of the quadriceps muscles. The basis of muscular exhaustion also requires clarification. There is no direct evidence that the problem arises from occlusion of the arteries by muscular pressure, rather than an inadequate development of the capillary bed. However, Barcroft & Dornhorst (1949) have shown that muscle flow can be limited by rhythmic exercise, and this explanation of the local exhaustion during cycling is supported by the accumulation of lactate at work-loads as low as 50% of aerobic power (Åstrand, 1960).

Annex

TECHNIQUE FOR MICRO-ESTIMATIONS OF BLOOD LACTATE

Blood lactate levels were measured on 100-μl samples, collected from the heated finger-tip in disposable capillary tubes with a volume tolerance of 1%. In view of the small size of the samples, considerable care was taken to wash all traces of sweat from the finger-tip prior to lancing.

The technique of analysis was a modification of the Boehringer enzymatic method (Loomis & Alto, 1961; Mohme-Lundholm et al., 1965). The contents of the capillary pipettes were transferred to small conical Pyrex tubes containing 400 μl–900 μl trichloroacetic acid (depending upon the anticipated lactate concentration); the tubes were centrifuged as rapidly as possible (to avoid continuing glycolysis), and a suitable volume of supernatant (usually 100 μl) was added to 2 ml glycine/hydrazine buffer carefully adjusted to pH 9.2. The whole solution was then transferred to the reaction tube containing 200 μl 0.027 M 2–4 dinitrophenylhydrazine and 50 μl lactic dehydrogenase (nominal concentration 2.5 units/ml). The colour was read at 340 nm after 50 min incubation at 70°F (21°C).

" Blank " solutions were prepared by treating 100-μl aliquots of trichloroacetic acid in an identical manner.

Recovery experiments were performed on standard solutions of L-lactate; lithium lactate was preferred to calcium lactate for this purpose, since the latter tended to be hygroscopic. On any given day, values could be replicated to within 1%–3%, but when different batches of reagents were used on different days, the absorbence of standard solutions varied by up to 5%.

Test samples were obtained 2 min and 4 min after ceasing exercise. In 13 of the present group of subjects, the 2-min concentrations were up to 8 mg/100 ml higher than the 4-min concentrations, in 2 subjects the mean readings were identical, and in 9 subjects the 4-min readings were up to 8 mg/100 ml higher. Although small, these differences were consistent in a given subject, and accordingly the figures reported in Tables 2 and 5 are based on the highest values attained by each individual.

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RÉSUMÉ

Un groupe de travail international s'est réuni à Toronto, Canada, pendant l'été de 1967, sous les auspices du Programme biologique international, en vue de parvenir à un accord sur les méthodes à utiliser pour mesurer la capacité de travail. On a choisi la consommation maximale d'oxygène $(\dot{V}_{O_2})_{max}$, mesurée directement, comme critère de l'aptitude cardio-vasculaire, et l'on a procédé à l'évaluation des méthodes de mesure du $(\dot{V}_{O_2})_{max}$ en soumettant 24 sujets à des épreuves répétées. Il est apparu que c'est pendant une course en montée sur tapis roulant que le $(\dot{V}_{O_2})_{max}$ était le plus élevé; il était respectivement de 3,4 et 6,6% plus faible pendant l'épreuve des marches et celle de la bicyclette ergométrique. Les sujets ont présenté des signes d'épuisement général vers la fin de l'épreuve sur tapis roulant, tandis que sur la bicyclette ergométrique, c'est une fatigue locale des muscles quadriceps qui a mis fin à l'épreuve. Pendant l'exercice sur bicyclette, le volume maximal des battements systoliques était inférieur de 13 ml à ce qu'il était pendant la course sur tapis roulant.

Le tapis roulant est recommandé pour mesurer le $(\dot{V}_{O_2})_{max}$ en laboratoire, alors qu'on aura plutôt recours aux marches ou à la bicyclette ergométrique lorsque les épreuves ont lieu sur le terrain. Lorsque les épreuves maximales sont pratiquées en série discontinue, les sujets acquièrent un certain entraînement; avec la technique continue (augmentation de la charge toutes les 2 minutes), on obtient des valeurs du $(\dot{V}_{O_2})_{max}$ très voisines et il semble que ce soit la méthode de choix pour les enquêtes à grande échelle.

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